Photosynthesis

Photosynthesis is carried out by plants, algae, photosynthetic protists, and cyanobacteria.

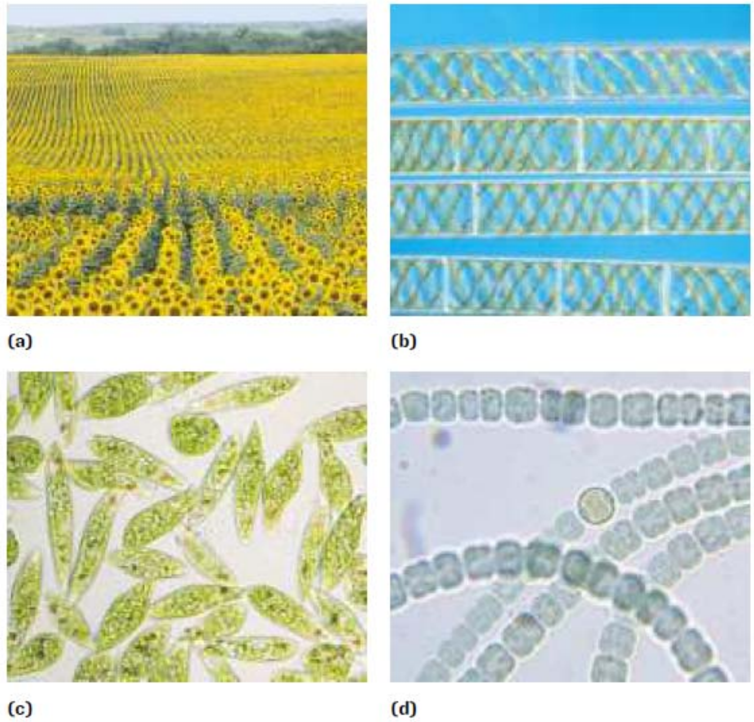


Figure 1
(a) Sunflowers
(b) *Spirogyra*, a photosynthetic alga
(c) *Euglena gracilis*, a photosynthetic protist
(d) *Anabaena*, a cyanobacterium

Algal and plant cells contain chloroplasts, most often found in the mesophyll and guard cells of plant leaves.

Overall equation for photosynthesis:

$$6CO_{2(g)} + 12H_2O_{(l)} + \text{light energy} \rightarrow C_6H_{12}O_{6\,(aq)} + 6H_2O_{(g)} + 6O_2$$

Chloroplasts have an outer membrane and an inner membrane. The inner space contains a semi-liquid material called stroma with a system of membrane bound sacs called thylakoids, which are stacked on top of one another to form grana. Thylakoid membranes contain chlorophyll molecules and electron transport chains.

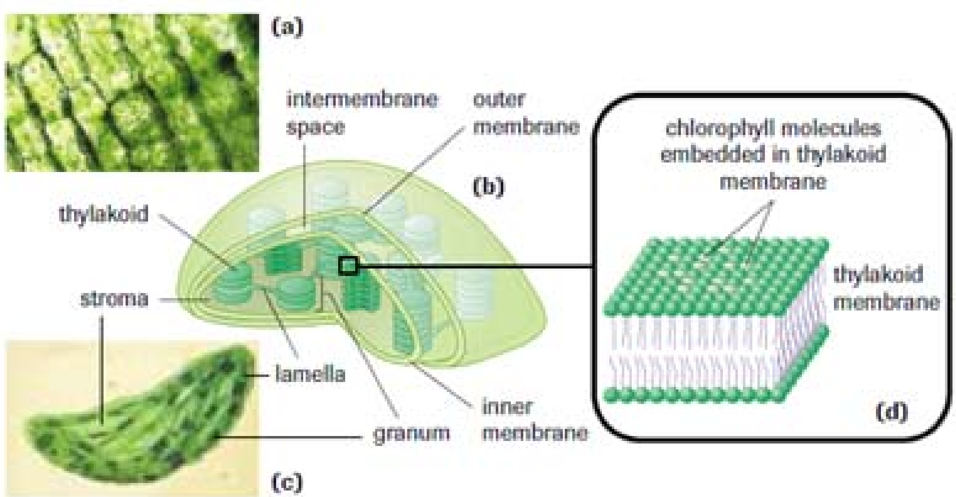


Figure 13
(a) Chloroplasts within plant cells
(b) An artist's representation of a chloroplast, showing key components
(c) An electron micrograph of a chloroplast
(d) Chlorophyll molecules in the thylakoid membrane

Photosynthesis takes place in the chloroplasts in three steps:

Stage 1: Capturing light energy
Stage 2: Synthesizing ATP and NADPH
Stage 3: The Calvin cycle (carbon fixation)

- Light is a energy that travels in wave packets called photons

Creation of Oxygen – Light dependant RXN

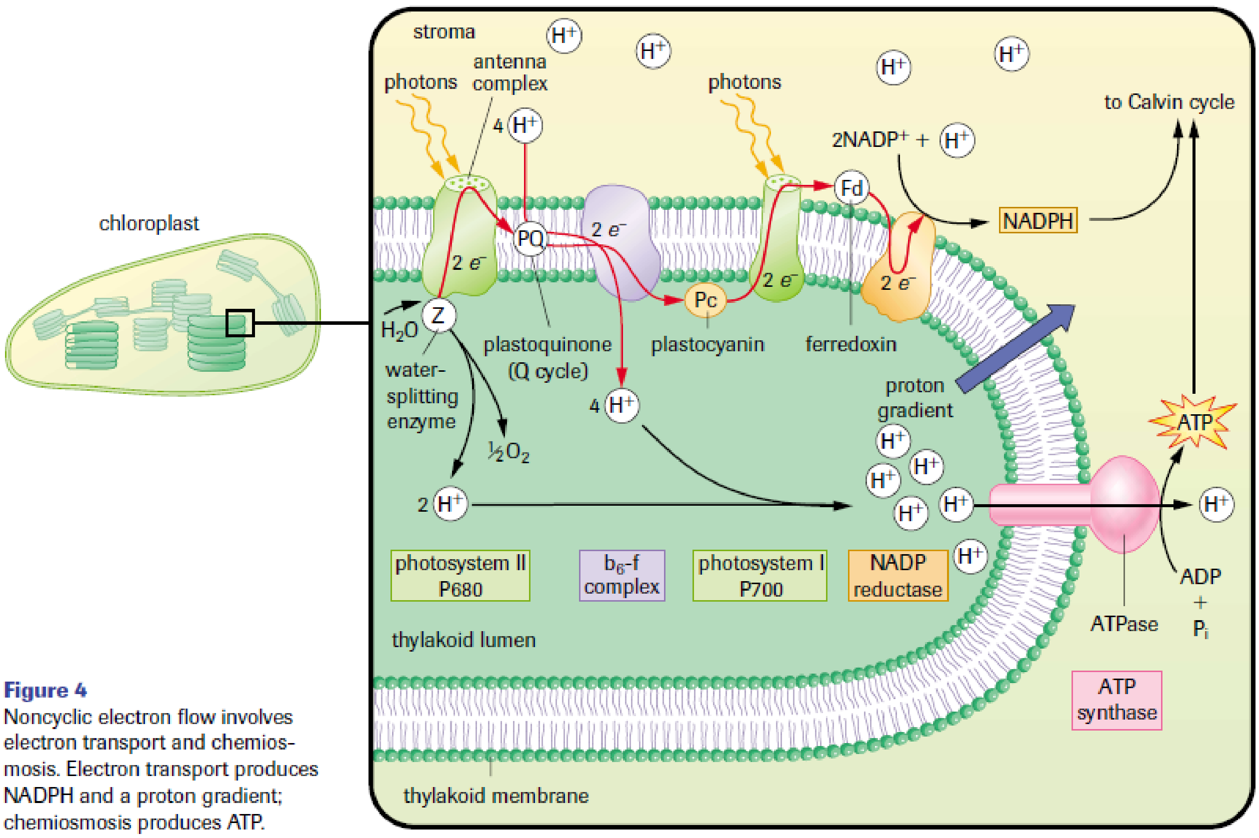
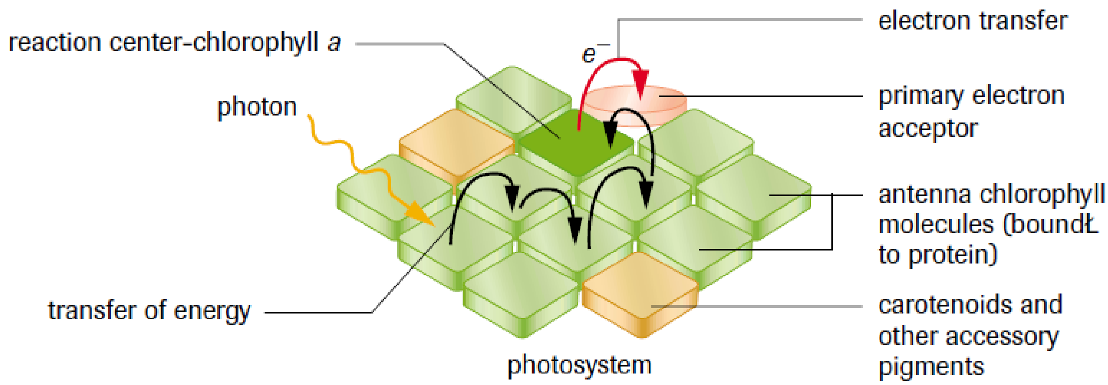


Figure 4
Noncyclic electron flow involves electron transport and chemiosmosis. Electron transport produces NADPH and a proton gradient; chemiosmosis produces ATP.

- Photons strike photosystem II and excite an electron of chlorophyll P680
- The electron is transferred to an electron carrier called plastoquinone (PQ)
- Then the electron enters an electron transport chain (this process happens twice, causing two electrons to pass through the chain)
- A protein splits water into oxygen, hydrogen ions, and electrons, two of which replace the missing electrons in chlorophyll P680.
- Oxygen leaves the chloroplast as a byproduct, and the hydrogen atoms remain in the thylakoid lumen
- The electrons that leave photosystem II pass through the Q cycle, which transports protons from the stroma into the thylakoid lumen,

- Four protons move into the lumen for each pair of electrons that passes through the transport chain.
- The electrons then move through plastocyanin, Pc, and other components of the electron transport chain and replace the two electrons that were lost by photosystem I when it was struck by photons.
- The electrons then move to the enzyme NADP reductase that uses the two electrons and H^+ ions from the stroma to reduce $NADP^+$ to NADPH.
- Protons that accumulate in the thylakoid lumen contribute to an electrochemical gradient that drives the phosphorylation of ADP to ATP.
- As protons move through the ATPase complex from the thylakoid lumen into the stroma, ATP is formed.

Photosystems



- Photosystems contain chlorophyll molecules, accessory pigments, and proteins embedded in a thylakoid membrane. The antenna complex of a photosystem is composed of chlorophyll molecules and accessory pigments set in a protein matrix and embedded in the thylakoid membrane.
- An antenna pigment absorbs a photon and transfers the energy from pigment to
- pigment until it reaches a chlorophyll a molecule, where an electron of the chlorophyll absorbs the energy
- Chloroplast membranes contain two types of photosystems:
  - Photosystem I, called P700 because its absorption spectrum peaks at a wavelength of 700 nm (red light)
  - Photosystem II is called P680 because it is best at absorbing photons with a wavelength of 680 nm (red light)
- Photosystems, through the light reactions, transfer their energy to ADP and NADP+, forming ATP and NADPH.
- In spring and summer, leaves appear green because of the high concentration of chlorophyll. In autumn, plants stop producing chlorophyll, causing the yellow, red, and brown colours of autumn leaves to show.

Calvin Cycle – Light Independent RXN

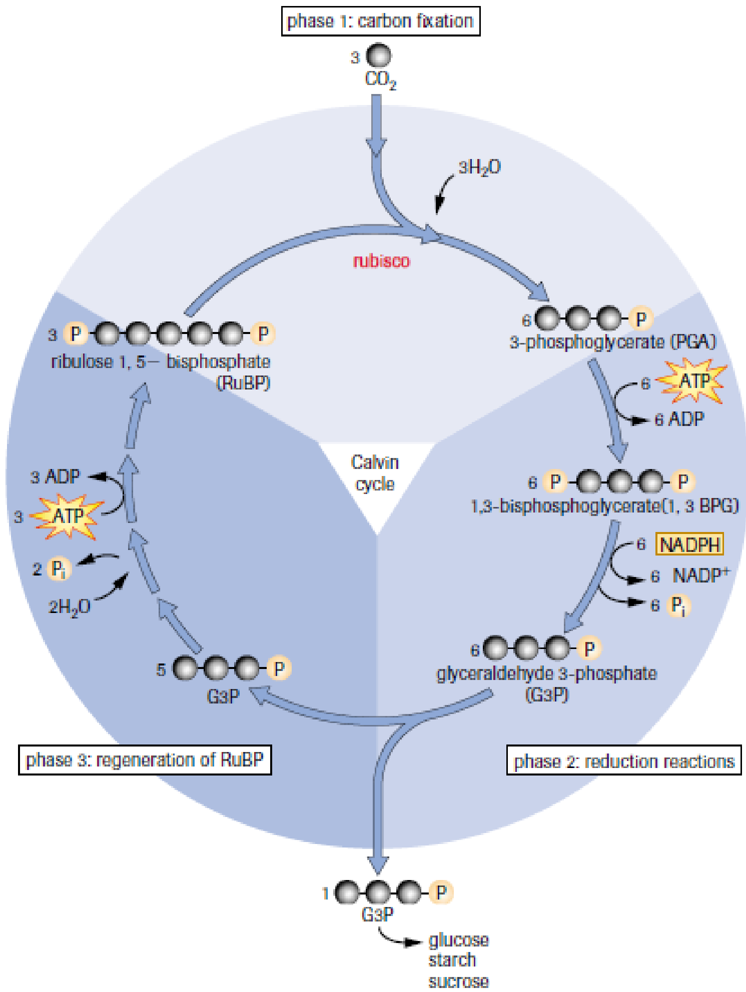


Figure 9
The Calvin cycle can be divided into three phases: carbon fixation, reduction reactions, and RuBP regeneration.

What we need to know about the Calvin cycle:

- CO_2 enters the cell and add to the 5-carbon ribulose, 1, 5-biphosphate (RuBP) molecule
- This 6 carbon molecule is broken into two, 3 carbon molecules
- This fixation of CO_2 is catalyzed by rubisco
- In the reduction reactions, PGA molecules arre phosphorelated by ATP and the resulting molecule is reduced by NADPH to G3P (a sugar) and one of the 6 G3P molecules exit the cycle
    - o G3P may be converted into glucose and polymerized into starch, or it may be transported into the cytoplasm and used to produce glucose and sucrose
- The remaining 5 G3P are rearranged to create 3 molecules of RuBP, completing the cycle.

Table 1 Comparison of the Overall Reactions

	Respiration	Photosynthesis
reactants	organic molecules (e.g., glucose)	$CO_2 + H_2O$
products	$CO_2 + H_2O$	organic molecules (e.g., glucose)
energy	released	stored

Table 2 Electrons

	Respiration	Photosynthesis
source	organic molecules (e.g., glucose)	water
carrier(s)	NAD^+, FAD	$NADP^+$

Table 3 Electron Transport System

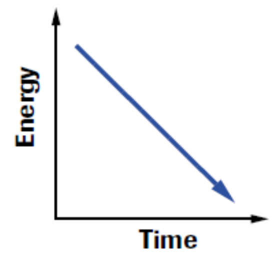
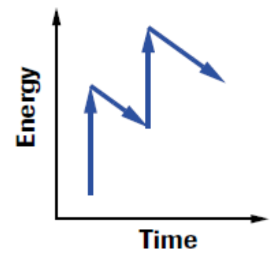
	Respiration	Photosynthesis
energy profile		
electron source	NADH and $FADH_2$	water
electron sink	oxygen	NADPH
products	ATP	ATP and NADPH

Table 4 ATP Synthesis

	Respiration	Photosynthesis
H^+ ions pumped by ETC	yes	yes
ATP synthesis by chemiosmosis	yes	yes
membrane-embedded ATPase complex	yes	yes

Table 5 Organelle Structure and Function

	Mitochondrion	Chloroplast
	(cristae)	(thylakoid)
inner membrane functions	electron transport H^+ ion transport ATP synthesis	electron transport H^+ ion transport ATP synthesis
contains DNA, ribosomes, etc. for replication	yes	yes
location of H^+ reservoir	intermembrane space	thylakoid lumen
location of ATP synthesis	matrix	stroma

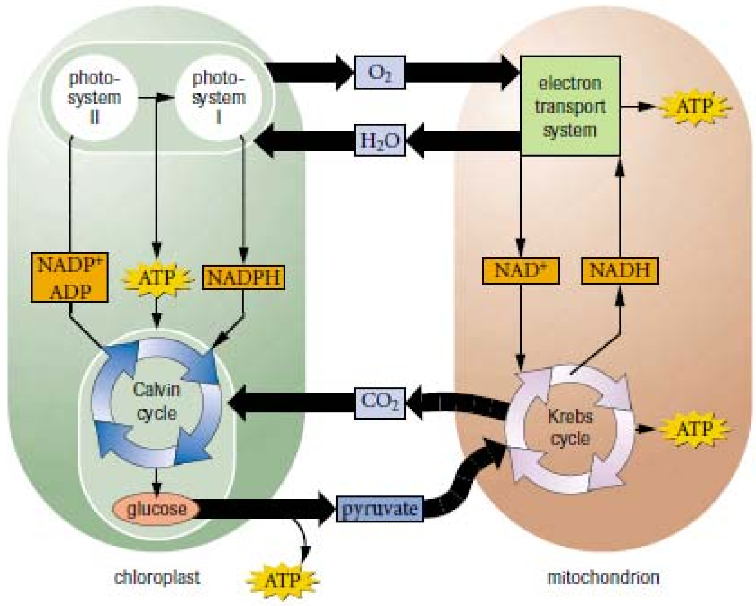


Figure 1
The food/energy cycle. Photosynthesis uses the products of cellular respiration and cellular respiration uses the products of photosynthesis.

* All Images Retrieved from Nelson Biology 12